Appendix D

Stress Calculations of the Injection Well Tubulars

Geostock Sandia

APPENDIX D
Strategic Biofuels
Louisiana Green Fuels Site
Plant Wells -1, 2 & 3
Tubular Design Calculations

1 Potable Water String

The greatest burst, collapse and tension stresses induced over the life of the 24-inch potable water casing occur during its installation.

A. **Burst**: The burst pressure of the casing is governed by conditions present at the casing shoe and at surface. The shoe scenario (*Option 1*)assumes that the formation will fracture before the casing ruptures, while the surface scenario assumes that a kick has occurred, and the casing contains only gas. The second option is during normal two plug cementing if the shoe were to become plugged. For this option, the maximum burst pressure at the shoe and surface will occur if the float shoe plugs during cementing resulting in a sudden pressure increase in the casing during cementing. The greater of the two anticipated pressures will dictate the required burst strength of the casing.

Option 1

$$P_{shoe} = (FG + SF) \times 0.052 \times D_{csg} - MW \times 0.052 \times D_{csg}$$

and

$$P_{surf} = P_{shoe} - \left(G_g \times D_{csg}\right)$$

where,

P_{shoe}	=	Maximum anticipated shoe pressure, psi
P_{surf}	=	Maximum anticipated surface pressure, psi
FG	=	Estimated fracture pressure at shoe, lb/gal
SF	=	Burst loading safety factor, (1.5 lb/gal)
D_{csg}	=	Casing setting depth, feet
MW	=	Mud Weight of drilling fluid, lb/gal
0.052	=	Conversion factor, psi-gal/ft-lb
Gg	=	Gas gradient, (0.115 psi/ft)

P_{shoe} = (12.5 + 1.5) x 0.052 x 300 – 9.0 x 0.052 x 300
P_{shoe} = 78 psi

P_{surf} = 78 – (0.115 x 300)
P_{surf} = 43.5 psi

Option 2

$$P_{shoe} = P_{pump} + CD_{lead} \times 0.052 \times D_{cmtl} + CD_{tail} \times 0.052 \times D_{cmtt} + (FG + SF) \times 0.052 \times D_{csg} - MW \times 0.052 \times D_{csg}$$

and

$$P_{surf} = P_{pump} - (0)$$

where,

P_{shoe}	=	Maximum anticipated shoe pressure, psi
P_{surf}	=	Maximum anticipated surface pressure, psi,
P_{pump}	=	Maximum anticipated pump applied pressure, psi, assume 500 psi
CD_{lead}	=	Estimated density of lead cement slurry, lb/gal
CD_{tail}	=	Estimated density of tail cement slurry, lb/gal
FG	=	Estimated fracture pressure at shoe, lb/gal
SF	=	Burst loading safety factor, (1.5 lb/gal)
D_{csg}	=	Casing setting depth, feet
D_{cmtl}	=	Estimated height of lead cement column in casing, feet
D_{cmtt}	=	Estimate height of tail cement column in casing, feet
D_{csg}	=	Estimate height of drilling mud column in casing cementing, feet
MW	=	Mud Weight of drilling fluid, lb/gal
0.052	=	Conversion factor, psi-gal/ft-lb
Gg	=	Gas gradient, (0.115 psi/ft)

P_{shoe} = 500 + (12.5 x 0.052 x 200 + 14.8 x 0.052 x 83 + 9.0 x 0.052 x 17) – 9.0 x 0.052 x 300

P_{shoe} = 561.8psi

P_{surf} = 500 – (0)
P_{surf} = 500 psi

For Plant Well 1, 2, & 3:

The burst pressure rating of the 24-inch O.D., 174 lb/ft, Grade K-55 surface casing is 2,760 psi, which results in a safety factor of 4.91 (2760/561.8) for Option 2.

B. **Collapse**: The collapse pressure of the casing is governed by conditions present at the shoe during cementing of the casing with an inner string job. The scenario assumes that the casing is field with freshwater inside and plug or blockage occurs at surface when the cement reaches surface resulting a 500-psi pressure spike at the shoe. The anticipated pressure will dictate the required collapse strength of the casing.

$$P_{shoe} = P_{pump} + (MW_{lead} \times 0.052 \times D_{lead}) + (MW_{tail} \times 0.052 \times D_{tail}) - (MW_{FW} \times 0.052 \times D_{FW})$$

where,

P_{shoe}	=	Maximum anticipated external shoe pressure, psi
P_{pump}	=	Maximum pump pressure at surface, psi
MW_{lead}	=	Mud Weight of lead cement, lb/gal
MW_{tail}	=	Mud Weight of tail cement, lb/gal
MW_{FW}	=	Mud Weight of Freshwater, lb/gal
D_{lead}	=	Height of Lead Cement, feet
D_{tail}	=	Height of tail slurry, feet
D_{FW}	=	Height of freshwater in casing, fet
0.052	=	Conversion factor, psi-gal/ft-lb

P_{shoe} = 500 + (12.5 x 0.052 x 200) + (14.8 x 0.052 x 100) – (8.34 x 0.052 x 300)
P_{shoe} = 577 psi

For Plant Well 1, 2, & 3:

The collapse pressure rating of the 24-inch O.D., 174 lb/ft, Grade K-55 surface casing is 1,160 psi, which results in a safety factor of 2.0 (1160/577)

C. Tension: The tensile strength of the casing is governed by the unit tubular weight and buoyancy effects.

$$W_{\max} = W_{csg} \times D_{csg} - MW \times A_{csg} \times 0.052 \times D_{csg}$$

where,

W_{max}	=	Maximum tensile weight at worst case, lbs
W_{csg}	=	Unit casing weight, lb/ft
D_{csg}	=	Casing setting depth, feet
MW	=	Mud Weight of drilling fluid, lb/gal
A_{csg}	=	Cross-sectional area of casing, sq. in.
0.052	=	Conversion factor, psi-gal/ft-lb

For Plant Well 1, 2, & 3:

W_{max} = 174 x 300 – 9.0 x 50.39 x 0.052 x 300

W_{max} = 45,125 lbs

The tensile rating of the 24-inch O.D., 174.0 lb/ft, Grade K-55 casing is 2,771,000 lbs, which results in a safety factor of 61.4 (2,771,000/45,125).

The tensile rating of the Tenaris ER connection on the 24-inch O.D., 174.0 lb/ft, Grade K-55 casing is 2,771,000 lbs, which results in a safety factor of 61.4 (2,771,000/45,125).

2 Surface Casing

The greatest burst, collapse and tension stresses induced over the life of the surface casing occur during its installation.

A. Burst: The burst pressure of the casing is governed by conditions present at the casing shoe and at surface. The maximum burst pressure at the shoe and surface will occur if the float shoe plugs during cementing resulting in a sudden pressure increase in the casing during cementing. The greater of the two anticipated pressure at surface or the shoe will dictate the required burst strength of the casing.

$$P_{shoe} = P_{pump} + CD_{lead} \times 0.052 \times D_{cmtl} + CD_{tail} \times 0.052 \times D_{cmtt} + (FG + SF) \times 0.052 \times D_{csg} - MW \times 0.052 \times D_{csg}$$

and

$$P_{surf} = P_{pump} - (0)$$

where,

P_{shoe}	=	Maximum anticipated shoe pressure, psi
P_{surf}	=	Maximum anticipated surface pressure, psi,
P_{pump}	=	Maximum anticipated pump applied pressure, psi, assume 500 psi
CD_{lead}	=	Estimated density of lead cement slurry, lb/gal
CD_{tail}	=	Estimated density of tail cement slurry, lb/gal
FG	=	Estimated fracture pressure at shoe, lb/gal
SF	=	Burst loading safety factor, (1.5 lb/gal)
D_{csg}	=	Casing setting depth, feet
D_{cmtl}	=	Estimated height of lead cement column in casing, feet
D_{cmtt}	=	Estimate height of tail cement column in casing, feet
D_{csg}	=	Estimate height of drilling mud column in casing cementing, feet
MW	=	Mud Weight of drilling fluid, lb/gal
0.052	=	Conversion factor, psi-gal/ft-lb
Gg	=	Gas gradient, (0.115 psi/ft)

P_{shoe} = *500* + (12.5 x 0.052 x 681 + 14.8 x 0.052 x 306 + 9.0 x 0.052 x 213) – 9.0 x 0.052 x 1200

P_{shoe} = 616.5 psi

P_{surf} = 500 – (0)

P_{surf} = 500 psi

For Plant Well 1, 2, & 3:

The burst pressure rating of the 18-5/8-inch O.D., 87.5 lb/ft, Grade K-55 surface casing is 2,250 psi, which results in a safety factor of 3.65 (2250/616.5).

B. Collapse: The collapse pressure of the casing is governed by conditions present at the shoe during cementing of the casing. The scenario assumes that the casing is field with freshwater following the cementing. The anticipated pressure will dictate the required collapse strength of the casing.

$$P_{shoe} = (MW_{lead} \times 0.052 \times D_{lead}) + (MW_{tail} \times 0.052 \times D_{tail}) - (MW_{FW} \times 0.052 \times D_{shoe})$$

where,

P_{shoe}	=	Maximum anticipated external shoe pressure, psi
MW_{FW}	=	Mud Weight of freshwater, lb/gal
MW_{lead}	=	Mud Weight of lead cement, lb/gal
MW_{tail}	=	Mud Weight of tail cement, lb/gal
D_{shoe}	=	Depth of casing shoe, feet
D_{lead}	=	Depth of Lead Cement, feet
D_{tail}	=	Height of tail slurry, feet
0.052	=	Conversion factor, psi-gal/ft-lb

P_{shoe} = (12.5 x 0.052 x 900) + (14.8 x 0.052 x 300) - (8.34 x 0.052 x 1200)

P_{shoe} = 295.5 psi

For Plant Well 1, 2, & 3:

The collapse pressure rating of the 18-5/8-inch O.D., 87.5 lb/ft, Grade K-55 surface casing is 630 psi, which results in a safety factor of 2.2 (650/295.5).

C. Tension: The tensile strength of the casing is governed by the unit tubular weight and buoyancy effects.

$$W_{\max} = W_{csg} \times D_{csg} - MW \times A_{csg} \times 0.052 \times D_{csg}$$

where,

W_{max}	=	Maximum tensile weight at worst case, lbs
W_{csg}	=	Unit casing weight, lb/ft
D_{csg}	=	Casing setting depth, feet
MW	=	Mud Weight of drilling fluid, lb/gal
A_{csg}	=	Cross-sectional area of casing, sq. in. 18-5/8" = 24.86 sq inches
0.052	=	Conversion factor, psi-gal/ft-lb

For Plant Well 1, 2, & 3:

W_{max} = 87.5 x 1200 – 9.0 x 24.86 x 0.052 x 1200

W_{max} = 91,038.6 lbs

The tensile rating of the 18-5/8-inch O.D., 87.5 lb/ft, Grade K-55 surface casing is 1,367,000 lbs, which results in a safety factor of 15.0 (1,367,000/91,039).

The tensile rating of the buttress connection on the 18-5/8-inch O.D., 87.5 lb/ft, Grade K-55 surface casing is 1,427,000 lbs, which results in a safety factor of 15.7 (1,427,000/91,039).

3 Intermediate Casing

The greatest burst, collapse and tension stresses induced over the life of the intermediate casing occur during its installation.

A. **Burst**: The greatest rupture stresses induced over the life of the protection casing occur during the cementing of the casing. This scenario assumes that lost circulation occurs, and the float equipment plugs up with all the cement inside the casing. The drilling fluid is used as the displacement fluid, and the maximum allowable surface pressure during this operation is 1,000 psig.

$$P_{shoe} = MW_{lead} \times 0.052 \times H_{lead} + MW_{tail} \times 0.052 \times H_{tail} - MW \times 0.052 \times L_{csg} + MASP_{cmt}$$

where,

P_{shoe}	=	Maximum anticipated shoe pressure, psi
MW_{lead}	=	Mud Weight of Lead Cement, lb/gal
H_{lead}	=	Height of lead cement, feet
MW_{tail}	=	Mud Weight of Tail Cement, lb/gal
H_{tail}	=	Height of tail cement, feet
MW	=	Mud Weight of drilling fluid, lb/gal
L_{csg}	=	Affected length of casing, feet
Cap_{csg}	=	Casing capacity (13-3/8” = 0.1521 bbl/ft)
V_{lead}	=	Volume of lead cement from cementing recommendation
V_{tail}	=	Volume of tail cement from cementing recommendation
0.052	=	Conversion factor, psi-gal/ft-lb
$MASP_{cmt}$	=	Maximum allowable surface pressure during cementing, psig

For Plant Well 1, 2, & 3:

The highest collapse pressure will occur during the second stage cementing for the 13-3/8-inch intermediate casing. Using the cementing volume calculations, the lead cement volume is 232.1 bbl and the density is 13.5 lb/gal. The tail cement volume is 56.6 bbl and the density is 14.5 lb/gal.

H_{lead} = Volume of lead cement /Casing capacity
$H_{lead} = 232.1/0.1521$
$H_{lead} = 1{,}526$ feet

H_{tail} = Volume of tail cement /Casing capacity
$H_{tail} = 56.6/0.1521$
$H_{tail} = 272$ feet

Since the density of the drilling fluid inside the casing equals the drilling fluid density in the casing annulus, the affected length of casing is the total length of the lead and tail cements (1,526 + 272), or 1,798 feet (total depth for this stage is 3,000 ft). Inserting these values into the master equation:

$P_{shoe} = (13.5 \text{ x } 0.052 \text{ x } 1{,}526) + (14.5 \text{ x } 0.052 \text{ x } 272) – (9.0 \text{ x } 0.052 \text{ x } 1{,}798) + 1{,}000$
$P_{shoe} = 1{,}071.3 + 205.1 – 841.5 + 1{,}000$
$P_{shoe} = 1{,}434.9$ psi

The burst pressure rating of the 13-3/8-inch O.D., 61.0 lb/ft, Grade K-55 intermediate casing is 3,090 psi, which results in a safety factor of 2.15 (3,090/1,434.9).

B. **Collapse**: The collapse pressure of the casing is governed by conditions present at the shoe and at the top of tail cement during cementing of the casing. Highest collapse pressure from the cementing will be during the second stage cementing at 3,000 feet. The other possibility is if the wellbore were to bridge in the annulus above the top of the stage cement pumping resulting in an estimated 800 psi pressure surge over the hydrostatic pressure difference at the shoe. Both scenarios assume that the casing is filled with fresh water inside as the displacement fluid. The greater of the two anticipated pressures will dictate the required collapse strength of the casing.

P_{DV1} = (MW_{lead} x 0.052 x D_{lead}) + (MW_{tail} x 0.052 x L_{tail}) + (MW_M x 0.052 x D_M) – (MW_{fw} x 0.052 x D_{DV1}) and

P_{shoe} = (MW_{lead} x 0.052 x D_{tail}) +(MW_M x 0.052 x D_{shoe}) – (MW_{fw} x 0.052 x D_{shoe}) + 1,000 psi

where,

P_{shoe}	=	Maximum anticipated external shoe pressure, psi
P_{DV1}	=	Maximum anticipated external pressure at the stage tool at 3,000 ft, psi
MW_{lead}	=	Mud Weight of lead cement, lb/gal
MW_{tail}	=	Mud Weight of tail cement, lb/gal
MW_M	=	Mud Weight of drilling mud, lb/gal
MW_{fw}	=	Mud Weight of freshwater, lb/gal
D_{lead}	=	Height of Lead Cement, feet
D_{tail}	=	Height of Tail cement, feet
D_M	=	Height of drilling fluid, feet
D_{fw}	=	Height of fresh water, feet
D_{DV1}	=	Depth of 1^{st} cementing stage tool, feet
D_{shoe}	=	Depth of casing shoe, feet
0.052	=	Conversion factor, psi-gal/ft-lb

P_{DV1} = (13.5 x 0.052 x 1,250) + (14.5 x 0.052 x 300) + (9.0 x 0.052 x 1,450) – (8.33 x 0.052 x 3,000)

P_{DV1} = 482.8 psi

P_{shoe} = (16.02 x 0.052 x 900) + (9.0 x 0.052 x 3,000) – (8.33 x 0.052 x 3,900) + 800

P_{shoe} = 1,264.4 psi

For Plant Well 1, 2, & 3:

The collapse pressure rating of the 13-3/8-inch O.D., 61.0 lb/ft, Grade K-55 intermediate casing 3,000 feet is 1,540 psi during second stage cementing, which results in a safety factor of 3.19 (1,540/482.8).

The collapse pressure rating of the 13-3/8-inch O.D., 61.0 lb/ft, 13CR65 intermediate casing 3,900 feet is 1,620 psi during first stage cementing, which results in a safety factor of 1.28 (1,620/1,264.4).

C. **Tension**: The tensile strength of the casing is governed by the unit tubular weight and buoyancy effects.

$$W_{\max} = W_{csg} \times D_{csg} - MW \times A_{csg} \times 0.052 \times D_{csg}$$

where,

W_{max}	=	Maximum tensile weight at worst case, lbs
W_{csg}	=	Unit casing weight, lb/ft
D_{csg}	=	Casing setting depth, feet
MW	=	Mud Weight of drilling fluid, lb/gal
A_{csg}	=	Cross-sectional area of casing, sq. in. 13-3/8" = 17.487
0.052	=	Conversion factor, psi-gal/ft-lb

For Plant Well 1, 2, & 3:

W_{max} = 61.0 x 3,900 – 9.4 x 17.487 x 0.052 x 3,900

W_{max} = 204,564 lbs

The tensile rating of the 13-3/8-inch O.D., 61.0 lb/ft, Grade K-55 intermediate casing is 962,000 lbs, which results in a safety factor of 4.7 (962,000/204,564).

The tensile rating of the Buttress connection on the 13-3/8-inch O.D., 61.0 lb/ft, Grade K-55 intermediate casing is 1,169,000 lbs, which results in a safety factor of 5.71 (1,169,000/204,564).

4 Completion Casing

The greatest burst, collapse and tension stresses induced over the life of the intermediate casing occur during its installation.

A. **Burst**: The greatest rupture stresses induced over the life of the protection casing occur during the cementing of the casing. This scenario assumes that lost circulation occurs, and the float equipment plugs up with all the cement inside the casing. The drilling fluid is used as the displacement fluid, and the maximum allowable surface pressure during this operation is 1,000 psig.

$$P_{shoe} = MW_{lead} \times 0.052 \times H_{lead} + MW_{tail} \times 0.052 \times H_{tail} - MW \times 0.052 \times L_{csg} + MASP_{cmt}$$

where,

P_{shoe}	=	Maximum anticipated shoe pressure, psi
MW_{lead}	=	Mud Weight of Lead Cement, lb/gal
H_{lead}	=	Height of lead cement, feet
MW_{tail}	=	Mud Weight of Tail Cement, lb/gal
H_{tail}	=	Height of tail cement, feet
MW	=	Mud Weight of drilling fluid, lb/gal
L_{csg}	=	Affected length of casing, feet
Cap_{csg}	=	Casing capacity (9-5/8" = 0.0773 bbl/ft)
V_{lead}	=	Volume of lead cement from calculations
V_{tail}	=	Volume of tail cement from calculations
0.052	=	Conversion factor, psi-gal/ft-lb
$MASP_{cmt}$	=	Maximum allowable surface pressure during cementing, psig

For Plant Well 1, 2, & 3:

As there is not a lead cement, its' volume is zero bbls. The tail cement volume is 295.6 bbl and the density is 16.02 lb/gal.

H_{lead} = Volume of lead cement /Casing capacity

H_{lead} = 0/0.0773

H_{lead} = 0
H_{tail} = Volume of tail cement /Casing capacity
H_{tail} = 174/0.0773
H_{tail} = 2,251 feet

Since the density of the drilling fluid inside the casing equals the drilling fluid density in the casing annulus, the affected length of casing is the total length of the lead and tail cements (0 + 2,251), or 2,251 feet. Inserting these values into the master equation:

P_{shoe} = (0) + (16.02 x 0.052 x 2,251) – (9.6 x 0.052 x 2,251) + 1,000
P_{shoe} = 0 + 1,875.2 – 1,123.7 + 1,000 psi
P_{shoe} = 1,751.5 psi

The burst pressure rating of the 9-5/8-inch O.D., 36.0 lb/ft, Grade 22CR65 completion casing is 4,160 psi, which results in a safety factor of 2.38 (4,160/1,751.5).

The burst rating of the 9-5/8-inch O.D., 36.0 lb/ft, Grade K-55 completion casing (upper section of hole) is 3,520 psi. With the bottom of the Grade K-55 casing located at 3,000 feet, assumed hydrostatic pressure gradient inside and outside the casing should both be equal due to both being filled with 9.6 lb/gal drilling mud. The pressure at 3,000 feet is approximately 1,000 psi which results in a safety factor of 3.52 (3,520/1,000).

B. **Collapse**: The collapse pressure of the casing is governed by conditions present at the shoe during cementing of the casing. The scenario assumes that the casing is filled with drilling mud or water inside as the displacement fluid. The anticipated pressure will dictate the required collapse strength of the casing.

$$P_{shoe} = (MW_{lead} \text{ x } 0.052 \text{ x } D_{lead}) + (MW_{tail} \text{ x } 0.052 \text{ x } L_{tail}) - (MW \text{ x } 0.052 \text{ x } TD_{Casing})$$

where,

P_{shoe} = Maximum anticipated external shoe pressure, psi
MW_{lead} = Mud Weight of lead cement, lb/gal (Drilling Mud, Mud Flush)
MW_{tail} = Mud Weight of tail cement, lb/gal
D_{lead} = Depth of Lead Cement, feet
L_{tail} = Height of tail slurry, feet
0.052 = Conversion factor, psi-gal/ft-lb

Stage 1

P_{shoe} = (9.6 x 0.052 x 3,000) + (16.02 x 0.052 x 3,920) – (9.6 x 0.052 x 6,920)
P_{shoe} = 1,497.6 + 3,265.5 – 3,454.5 psi
P_{shoe} = 1,308.6 psi

For Plant Well 1, 2, & 3:

The collapse pressure rating of the 9-5/8-inch O.D., 36.0 lb/ft, Grade 22CR65 completion casing is 2,190 psi, which results in a safety factor of 1.67 (2,190/1,309).

The collapse pressure rating of the 9-5/8-inch O.D., 36.0 lb/ft, Grade K-55 completion casing (upper section of hole) is 2,020 psi. With the bottom of the Grade K-55 casing located at 3,000 feet, the pressure on the casing at 3,000 feet is:

P_{3000} = (12.5 x 0.052 x 2,500) + (15.6 x 0.052 x 500) – (8.33 x 0.052 x 3,000)
P_{3000} = 2,030.6 – 1,299.5 psi
P_{3000} = 731.1 psi

Pressure at 3,000 feet is 731.1 psi which results in a safety factor of 2.76 (2,020/731.1).

C. **Tension**: The tensile strength of the casing is governed by the unit tubular weight and buoyancy effects.

$$W_{\max} = W_{csg} \times D_{csg} - MW \times A_{csg} \times 0.052 \times D_{csg}$$

where,

W_{max}	=	Maximum tensile weight at worst case, lbs
W_{csg}	=	Unit weight of casing, lb/ft
D_{csg}	=	Setting depth of casing, feet
MW	=	Mud Weight of drilling fluid, lb/gal
A_{csg}	=	Cross-sectional area of casing (10.25 sq. in.)
D_{csg}	=	Casing setting depth, feet
0.052	=	Conversion factor, psi-gal/ft-lb

For Plant Well 1, 2, & 3:

W_{max} = (36 x 7000) – (9.6 x 10.25 x .052 x 7000)
W_{max} = 252,000 – 35,817.6
$\boldsymbol{W_{max}}$ = 216,182.4 lbs.

The tensile rating of the 9-5/8-inch O.D., 36.0 lb/ft, Grade K-55 completion casing tube is 564,000 lbs, which results in a safety factor of 2.6 (564,000/216,182.4).

The tensile rating of an API LTC connection on the 9-5/8-inch O.D., 36.0 lb/ft, Grade K-55 completion casing is 489,000 lbs, which results in a safety factor of 2.26 (489,000/216,182.4).

Injection Tubing

A. **Burst**: The greatest rupture stresses induced over the life of the injection tubing occur during injection operations. This scenario assumes that the maximum injection pressure is realized while injecting waste fluids at the maximum permitted specific gravity. The annular fluid is used as a backup.

$$P_{max} = P_{max\ inj} + (0.433 \text{ x } SG_{infl} \text{ x } D) - (0.433 \text{ x } SG_{aflI} \text{ x } D)$$

where,

P_{max}	=	Maximum internal pressure, psia
$P_{max\ inj}$	=	Maximum injection pressure, psia
SG_{injfl}	=	Maximum specific gravity of injection fluid (0.86)
D	=	Depth of tubing, feet
0.433	=	Pressure gradient, psi/ft
SG_{afl}	=	Specific gravity of annular fluid (1.08)

For Plant Well 1, 2, & 3:

P_{max} = 2,500 + (0.433 x 0.86 x 4,800) – (0.433 x 1.08 x 4,800)
P_{max} = 2,500 + 1,787.4 – 2,244.7
P_{max} = 2,042.7

The burst pressure rating of the 5-1/2-inch O.D., 20.0 lb/ft, 22CR65 tubing is 7,680 psi, which results in a design safety factor of 3.76 (7,680/2,042.7).

B. **Collapse**: The maximum loading condition for collapse pressure of the injection tubing is governed by conditions present during annular pressure testing of the well. This scenario assumes that the waste fluid inside the tubing is at its minimum specific gravity and the surface injection pressure is zero.

$$P_{max} = P_{maxan} + (0.433 \text{ x } SG_{afl} \text{ x } D) - (0.433 \text{ x } SG_{infl} \text{ x } D) - P_{swht}$$

where,

P_{max}	=	Maximum external pressure, psi
P_{maxan}	=	Maximum annular pressure, psi
$P_{swh}t$	=	Shut in wellhead tubing pressure, psi
SG_{afl}	=	Specific gravity of annular fluid (1.02)
D	=	Depth of tubing, feet
0.433	=	Pressure gradient, psi/ft
SG_{injfl}	=	Minimum specific gravity of injection fluid (0.84)

For Plant Wells 1, 2 and 3:

Since collapse pressure is calculated based on the annulus testing data, all three wells will be at the same test pressure and packer setting depth for annulus pressure testing. Therefore, the maximum pressure encountered by the wells will be the same. Plant wells 1 and 2 will have the max pressure on the 5.5-inch tubing and plant well 3 will have the pressure on the 7.0-inch tubing. The Plant well 3 inner tubing (4.5-inch) will encounter the maximum collapse pressure during a time when injection is being conducted down the outer injection tubing and no injection down the inner tubing.

$$P_{max} = 2{,}600 + (0.433 \text{ x } 1.08 \text{ x } 4{,}800) - (0.433 \text{ x } 0.84 \text{ x } 4800) - 1{,}100$$
$$P_{max} = 2{,}600 + 2{,}244.7 - 1{,}745.9 - 1{,}100$$
$$P_{max} = 1{,}998.8 \text{ psi}$$

The collapse pressure rating of the 5-1/2-inch O.D., 20.0 lb/ft, 22CR65 tubing is 7,540 psi, which results in a design safety factor of 3.77 (7,540/1,998.8) at the shoe. If a casing pressure test was performed with the tubing filled with brine that balanced the bottom hole pressure, then the maximum collapse pressure would be at surface with a P_{max} of the test pressure of 2,600 psi, which results in a design safety factor of 2.9 (7,540/2,600) at the shoe.

C. **Tension:** The tensile strength of the injection tubing is governed by the unit tubular weight, with effects from buoyancy included. The maximum tensile weight will be just prior to setting the tubing into the packer. Calculations assume the well is filled with 1.02 specific gravity annular fluid prior to setting each tubing string.

$$W_{max} = W_{ta} \text{ x } D \text{ x } K_b$$

where,

W_{max}	=	Maximum tensile weight at worst case, lbs
W_{ta}	=	Unit weight of injection tubing, lb/ft
D	=	Depth of tubing, feet
K_b	=	Bouyancy Factor

and,

$$K_b = \left(1 - \frac{SG_{afl} * 8.33}{65.44}\right)$$

where,

SG_{afl}	=	Specific gravity of annular fluid (1.08)
8.33	=	Conversion Factor
65.44	=	Conversion Factor

For Plant Wells 1, 2 and 3:

W_{max} = (20.0 x 4,800) x (1 – (1.08 x 8.33)/65.44)
W_{max} = 96,000 x 0.8625
$\boldsymbol{W_{max}}$ = 82,802 lbs.

The tensile rating of the body of the 5.5-inch O.D., 20.0 lb/ft, Grade 22CR65 injection tubing body is 379,000 lbs, which results in a safety factor of 4.58 (379,000 /82,802).

The tensile rating of the Tenaris Blue connection on the 5.5-inch O.D., 20.0 lb/ft, Grade 22CR65 injection tubing is 379,000 lbs, which results in a safety factor of 4.58 (379,000 /82,802).